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(54) Nitride Semiconductor Device and Method of Manufacturing the Same

(57) [Abstract]

[Subject] To provide a nitride semiconductor device capable of achieving a reduction of an operation voltage by reducing contact resistance with an electrode, and a method of manufacturing the same.

[Solving Means] In a semiconductor laser device 100, a buffer layer 2, an undoped GaN layer 3, an n-GaN contact layer 4, an n-InGaN crack prevention layer 5, an n-AlGaN clad layer 6, an MQW light emission layer 7, a p-AlGaN clad layer 8 and a p-GaN contact layer 9 are sequentially laminated on a (0001) plane of a sapphire substrate 1 in this order. A ridge portion is formed on the p-GaN contact layer 9 and the p-AlGaN clad layer 8, and a concave/convex shape is formed on an upper plane of the ridge portion. Furthermore, another concave/convex shape is formed on a surface of a predetermined region of the n-GaN contact layer 4, which is exposed by etching. Still furthermore, a p electrode 10 and an n electrode 11 are formed on the p-GaN contact layer 4 in which the concave/convex shape is formed.

[What is claimed is]

[Claim 1] A nitride semiconductor device is characterized in that a concave/convex shape is formed periodically or irregularly on a surface of an electrode formation region of a III group nitride semiconductor layer, and an ohmic electrode is formed on an upper plane of an electrode formation region in which the concave/convex shape is formed.

[Claim 2] The nitride semiconductor device according to claim 2, wherein the III group nitride semiconductor layer includes a substrate formed of a III group

nitride semiconductor.

[Claim 3] A nitride semiconductor device, in which a first III group nitride semiconductor layer of a first conductivity type, an active device region formed of a III group nitride semiconductor, and a second III group nitride semiconductor layer of a second conductivity type are sequentially formed on a substrate, characterized in that a first electrode formation region is located in a predetermined region of the first III group nitride semiconductor layer; a second electrode formation region is located in a predetermined region of the second III group nitride semiconductor layer; a concave/convex shape is formed on at least one of surfaces of the first and second electrode formation regions periodically or irregularly; an ohmic electrode of a first conductivity type is formed on the first electrode formation region; and an ohmic electrode of a second conductivity type is formed on the second electrode formation region.

[Claim 4] The nitride semiconductor device according to claim 3, wherein the first III group semiconductor nitride semiconductor layer of the first conductivity type includes a first contact layer; the second III group nitride semiconductor layer of the second conductivity type includes a second contact layer; the first electrode formation region is formed on a predetermined region of the first contact layer; the second electrode formation region is located in a predetermined region of the second contact layer; and the concave/convex shape is formed on at least one of the surface of the first electrode formation region of the first contact layer and the surface of the second electrode formation region of the second contact layer.

[Claim 5] The nitride semiconductor device according to claim 4, wherein the active device region including an optical waveguide constituting a resonator is a light emission layer; the first III group nitride semiconductor layer of the first conductivity type further includes a first clad layer; the second III group nitride semiconductor layer of the second conductivity type further includes a second clad

layer; and the concave/convex shape constituting a diffraction grating extending to an end face of the resonator parallely is formed on the surface of the second electrode formation region located in the second contact layer.

[Claim 6] The nitride semiconductor device according to any one of claims 3 to 5, wherein the concave/convex shape is constituted by a plurality of concave portions and a plurality of convex portions in stripes.

[Claim 7] A nitride semiconductor device, in which a first III group nitride semiconductor layer of a first conductivity type, an active device region formed of a III group nitride semiconductor, and a second III group nitride semiconductor layer of a second conductivity type are sequentially formed on one plane of an electrically conductive substrate, characterized in that a first electrode formation region is located in a predetermined region on the other plane of the electrically conductive substrate; a second electrode formation region is located in a predetermined region of the second III group nitride semiconductor layer; a concave/convex shape is formed at least on a surface of the first electrode formation region of the first and second electrode formation regions; an ohmic electrode of a first conductivity type is formed on the first electrode formation region; and an ohmic electrode of a second conductivity type is formed on the second electrode formation region.

[Claim 8] The nitride semiconductor device according to claim 7, wherein the electrically conductive substrate is constituted by gallium nitride.

[Claim 9] A method of manufacturing a nitride semiconductor device, characterized by comprising:

a step of forming an electrode formation region on a III group nitride semiconductor layer;

a step of forming a concave/convex shape on a surface of the electrode formation region; and

a step of forming an ohmic electrode on the electrode formation region where the concave/convex shape is formed.

[Claim 10] The method of manufacturing a nitride semiconductor device according to claim 9, wherein the III group nitride semiconductor layer includes a substrate formed of a III group semiconductor.

[Claim 11] The method of manufacturing a nitride semiconductor device according to claim 9 or 10, wherein the step of forming the concave/convex shape includes a step of etching the electrode formation region or a step of polishing the electrode formation region.

[Detailed Descriptions of the Invention]

[0001]

[Field of the Invention] The present invention relates to a nitride semiconductor device formed of a III-V group nitride semiconductor (hereinafter referred to as a nitride semiconductor) such as BN (boron nitride), GaN (gallium nitride), AlN (aluminium nitride), InN (indium nitride), and TlN (thallium nitride) or a mixed crystal formed of these materials, and a method of manufacturing the same.

[0002]

[Prior Arts] In recent years, as a light source for recording/replaying, which is used for high density and large capacity optical disc system, researches and developments of nitride semiconductor lasers emitting blue or violet light have been carried out.

[0003] Fig. 8 is a schematic cross sectional view showing an example of a conventional GaN semiconductor laser device. The semiconductor laser device shown in Fig. 8 is sequentially formed of a buffer layer 82, an undoped GaN layer 83, an n-GaN contact layer 84, an n-InGaN crack preventing layer 85, an n-AlGaN clad layer 86, a light emission layer 87 formed of InGaN, a p-AlGaN clad layer 88 and a p-GaN contact layer 89 on a C(0001) plane of a sapphire substrate 81.

[0004] A region extending from the p-GaN contact layer 89 to the p-AlGaN clad layer 88 is partially etched to a predetermined depth to be removed. Thus, a striped ridge portion consisting of the p-GaN contact layer 89 and the p-AlGaN clad layer 88 is formed, and flat portions are formed on the p-AlGaN clad layer 88. A p electrode 131 is ohmic-contacted onto the p-GaN contact layer 89 corresponding to each of the ridge portions. Furthermore, a region extending from the flat portion of the p-AlGaN clad layer 88 to the n-GaN contact layer 84 is partially removed by etching, and an n electrode formation region of the n-GaN contact layer 84 is exposed. An n electrode 132 is ohmic-contacted onto this exposed n electrode formation region.

[0005] An insulating film 95 formed of Si oxide such as SiO_2 is formed on both side planes of the ridge portion, an upper plane of the flat portion of the p-AlGaN clad layer 88, a side plane extending from the p-AlGaN clad layer 88 to the n GaN contact layer 84, and an upper plane of the n-GaN contact layer 84 except for a region where the n electrode 132 is formed.

[0006] It is noted that in the n-GaN contact layer 84, the n-InGaN crack preventing layer 85 and the n-AlGaN clad layer 86 of the foregoing semiconductor laser device, Si is used as an n type dopant. On the other hand, in the p-AlGaN clad layer 88 and the p-GaN contact layer 89, Mg is used as a p type dopant.

[0007]

[Subjects to be Solved by the Invention] In the p type semiconductor layers 88 and 89 of the foregoing semiconductor laser device, Mg which is the p type dopant is hardly activated. Therefore, in the p type semiconductor layers 88 and 89 of the semiconductor laser device, it is difficult to make carrier concentration high, and resistance in the p type semiconductor layers 88 and 89 becomes higher.

[0008] Particularly, since the resistance of the p-GaN contact layer 89 ohmic-contacting with the p electrode 131 is high, contact resistance between the p

electrode 131 and the p-GaN contact layer 89 increases. Therefore, it is difficult to obtain a good ohmic contact with the p electrode 131. Thus, an operation voltage becomes higher in the semiconductor laser device.

[0009] As described above, since the operation voltage becomes higher in the foregoing semiconductor laser device, a heating value during an operation becomes larger. Therefore, deterioration of the semiconductor laser device is significant, and a life time of the device is short.

[0010] Incidentally, the description as to the foregoing semiconductor laser device was made for the case where the n-GaN contact layer 84 is formed on order to effectively confine a light in the light emission layer 87, it is preferable to form an n-AlGaN contact layer formed of n-AlGaN.

[0011] However, in such an n-AlGaN contact layer, it is more difficult to make carrier concentration high, compared to an n-GaN contact layer. Therefore, in a case where the n-AlGaN contact layer is formed, the resistance of the contact layer becomes larger compared to a case where the n-GaN contact layer is formed, and the contact resistance with the n electrode 132 becomes higher. Accordingly, an operation voltage of the semiconductor laser device becomes higher in this case, and deterioration of the semiconductor laser device is more significant. Thus, a life time of the device becomes shorter.

[0012] On the other hand, researches of semiconductor devices using a GaN substrate have been promoted besides the sapphire substrate 8 as shown in Fig. 8.

[0013] In the semiconductor laser device using the GaN substrate, an n-GaN layer, an n-InGaN crack preventing layer, an n-AlGaN clad layer, an InGaN light emission layer, a p-AlGaN clad layer and a p-GaN contact layer, for example, are sequentially formed on one plane of the GaN substrate. A ridge portion is formed on the p-GaN contact layer and the p-AlGaN clad layer by etching. A p electrode is ohmic-contacted with an upper plane of the p-GaN contact layer corresponding

to this ridge portion. On the other hand, an n electrode is ohmic-contacted with another plane of the GaN substrate.

[0014] In the semiconductor laser device in which the n electrode is formed on the other plane of the GaN substrate, the GaN substrate needs to be rendered in an n type by doping Si to the GaN substrate.

[0015] Herein, as Si doping concentration in the GaN substrate is higher, crystallinity of the GaN substrate is more deteriorated. Accordingly, in order to obtain a good crystallinity in the GaN substrate, it is impossible to make the Si concentration in the GaN substrate fully high.

[0016] Incidentally, in fabricating the semiconductor laser device, a Ti film and an Al film, for example, are sequentially laminated, and an n electrode is formed on the other plane of the GaN substrate. Thereafter, a heating treatment is carried out. Herein, in the GaN substrate having the insufficient Si concentration as described above, contact resistance between the n electrode and the GaN substrate increases due to such a heat treatment, and an ohmic characteristic tends to be deteriorated.

[0017] As described above, the crystallinity of the GaN substrate and the contact resistance between the GaN substrate and the n electrode are in a trade-off relation. Accordingly, also in this case, an operation voltage of the semiconductor laser device becomes high, and a heating value during an operation thereof becomes larger. For this reason, in such a semiconductor laser device, deterioration of the device during the operation thereof is significant, and a life time thereof is short.

[0018] An object of the present invention is to provide a nitride semiconductor device capable of achieving a reduction in an operation voltage by reducing contact resistance with an electrode, and a method of manufacturing the same.

[0019]

[Means for Solving the Invention and Effects of the Invention] In a nitride semiconductor device according to a first invention, a concave/convex shape is formed periodically or irregularly on a surface of an electrode formation region of a III group nitride semiconductor layer, and an ohmic electrode is formed on an upper plane of an electrode formation region in which the concave/convex shape is formed.

[0020] In the nitride semiconductor device according to the present invention, the ohmic electrode is formed on the upper plane of the electrode formation region of the III group nitride semiconductor layer in which the concave/convex shape is formed. For this reason, a contact area between the ohmic electrode and the electrode formation region of the III group nitride semiconductor layer becomes larger compared to a case where an ohmic electrode is formed on an upper plane of an electrode formation region of a III group nitride semiconductor layer having a flat surface.

[0021] Accordingly, in such a nitride semiconductor device, it is possible to achieve a reduction in an operation voltage by reducing contact resistance between the electrode formation region of the III group nitride semiconductor layer and the ohmic electrode. Thus, with respect to the nitride semiconductor device, it is possible to realize the nitride semiconductor device which reduces a heating value during its operation and shows a long life time and high reliability.

[0022] Furthermore, the III group semiconductor layer may include a substrate formed of a III group semiconductor. In this case, since the concave/convex shape is formed on an electrode formation region of the substrate, it is possible to enlarge contact area between the electrode formation region of the substrate and the ohmic electrode. With such constitution, it is possible to reduce contact resistance between the electrode formation region formed on the substrate and the ohmic electrode.

[0023] A nitride semiconductor device according to a second invention is one, in which a first III group nitride semiconductor layer of a first conductivity type, an active device region formed of a III group nitride semiconductor, and a second III group nitride semiconductor layer of a second conductivity type are sequentially formed on a substrate, characterized in that a first electrode formation region is located in a predetermined region of the first III group nitride semiconductor layer; a second electrode formation region is located in a predetermined region of the second III group nitride semiconductor layer; a concave/convex shape is formed on at least one of surfaces of the first and second electrode formation regions periodically or irregularly; an ohmic electrode of the first conductivity type is formed on the first electrode formation region; and an ohmic electrode of a second conductivity type is formed on the second electrode formation region.

[0024] Herein, the active device region of the nitride semiconductor device includes, for example, a light emission layer and an activation layer of a light emitting diode device and a semiconductor laser device; a core layer of a wave guide device; an I layer of a PIN photo-diode; pn junction portions of a photo-diode and an HBT (hetero junction bipolar transistor); a channel portion of an FET (filed effect transistor) and the like.

[0025] In the nitride semiconductor device according to the present invention, the concave/convex shape is formed on at least one of the surfaces of the first and second electrode formation regions. For this reason, a contact area between the first electrode formation region and the first ohmic electrode and/or a contact area between the second electrode formation region and the second ohmic electrode can be made to be large.

[0026] Accordingly, in such a nitride semiconductor device, it is possible to achieve a reduction in an operation voltage by reducing contact resistance between the first electrode formation region and the first ohmic electrode and/or contact

resistance between the second electrode formation region and the second ohmic electrode

[0027] In the foregoing nitride semiconductor device in which the reduction in the operation voltage is achieved, it is possible to reduce a heating value during an operation thereof. Accordingly, it is possible to realize the nitride semiconductor device which shows a long life time and high reliability.

[0028] The first III group semiconductor nitride semiconductor layer of the first conductivity type may include a first contact layer; the second III group nitride semiconductor layer of the second conductivity type may include a second contact layer; the first electrode formation region may be formed on a predetermined region of the first contact layer; the second electrode formation region may be located in a predetermined region of the second contact layer; and the concave/convex shape may be formed on at least one of the surface of the first electrode formation region of the first contact layer and the surface of the second electrode formation region of the second contact layer.

[0029] In this case, the concave/convex shape is formed on the surfaces of the first and second electrode formation regions of the first and second contact layers, and/or on the surface of the second electrode formation region of the second contact layer.

[0030] Accordingly, in such a nitride semiconductor device, a contact area between the first contact layer and the first ohmic electrode and/or a contact area between the second contact layer and the second ohmic electrode can be made to be large. For this reason, it is possible to achieve a reduction in an operation voltage by reducing contact resistance between the first contact layer and the ohmic electrode and/or contact resistance between the second contact layer and the second ohmic electrode.

[0031] Furthermore, the active device region including an optical wave guide

constituting a resonator may be a light emission layer; the first III group nitride semiconductor layer of the first conductivity type may further include a first clad layer; the second III group nitride semiconductor layer of the second conductivity type may further include a second clad layer; and the concave/convex shape constituting a diffraction grating extending in parallel with an end face of the resonator may be formed on the surface of the second electrode formation region located in the second contact layer.

[0032] Such a nitride semiconductor device corresponds to a distribution feedback (DFB) semiconductor laser device.

[0033] In the DFB semiconductor laser device, a refraction index of the light emission layer changes periodically depending on the concave/convex shape formed on the second contact layer, and hence a light generated in the light emission layer is a diffraction having a predetermined dimension. Accordingly, such a semiconductor laser device can perform a laser oscillation in a single vertical mode.

[0034] In the DFB semiconductor laser device as described above, an oscillation wavelength of a laser beam does not vary even in a case where a current value or a device temperature changes, and thereby it is possible to oscillate the laser beam having a constant wavelength stably. Therefore, the nitride semiconductor laser device having a good device characteristic can be realized.

[0035] Particularly, in such a DFB semiconductor laser device, a wavelength of the laser beam can be set to a desired value by adjusting a cycle of the concave/convex shape formed on the second contact layer. Accordingly, selectivity of the wavelength of the semiconductor laser device is broadened.

[0036] The concave/convex shape may be constituted by a plurality of striped concave portions and a plurality of striped convex portions. Formations of the plurality of striped concave portions and a plurality of striped convex portions in

the electrode formation region enable a contact area between the electrode formation region and the electrode to be widened.

[0037] A nitride semiconductor device according to a third invention is one, in which a first III group nitride semiconductor layer of a first conductivity type, an active device region formed of a III group nitride semiconductor, and a second III group nitride semiconductor layer of a second conductivity type are sequentially formed on one plane of an electrically conductive substrate; a first electrode formation region is located in a predetermined region on the other plane of the electrically conductive substrate, characterized in that a second electrode formation region is located in a predetermined region of the second III group nitride semiconductor layer; a concave/convex shape is formed on at least a surface of the first electrode formation region of the first and second electrode formation regions; an ohmic electrode of a first conductivity type is formed on the first electrode formation region; and an ohmic electrode of a second conductivity type is formed on the second electrode formation region.

[0038] In the nitride semiconductor device according to the present invention, the concave/convex shape is formed on the surface of the first electrode formation region located at least on the other plane of the substrate. For this reason, it is possible at least to make a contact area between the first electrode formation region and the first ohmic electrode large.

[0039] Accordingly, in such a nitride semiconductor device, it is possible to achieve a reduction in an operation voltage by reducing contact resistance at least between the first electrode formation region located on the other plane of the substrate and the first ohmic electrode.

[0040] In the foregoing nitride semiconductor device in which the reduction in the operation voltage is achieved, it is possible to reduce a heating value during an operation thereof. Accordingly, it is possible to realize the nitride semiconductor

device which shows a long life time and high reliability.

[0041] The electrically conductive substrate may be constituted by gallium nitride. In this case, a difference in lattice constants between the substrate and the first and second III group nitride semiconductor layers and/or the active device region becomes smaller. Therefore, in the first and second III group nitride semiconductor layers and the active device region, dislocations generated due to the difference of the lattice constants between the substrate and, the first and second III group nitride semiconductor layers or the active device region can be reduced. Accordingly, since good crystallinity is realized in these layers, an improvement in a device characteristic can be achieved in the nitride semiconductor device.

[0042] A method of manufacturing a nitride semiconductor device according to a fourth invention is characterized by comprising: a step of forming an electrode formation region on a III group nitride semiconductor layer; a step of forming a concave/convex shape on a surface of the electrode formation region; and a step of forming an ohmic electrode on the electrode formation region where the concave/convex shape is formed.

[0043] In the method of manufacturing a nitride semiconductor device according to the present invention, the concave/convex shape is formed on the upper surface of the electrode formation region of the III group nitride semiconductor layer where the concave/convex shape is formed, and the ohmic electrode is formed on the electrode formation region where the concave/convex shape is formed. Therefore, compared to the case where an ohmic electrode is formed on an electrode formation region of a III group nitride semiconductor layer having a flat surface, it is possible to enlarge a contact area between the ohmic electrode and the electrode formation region of the III group nitride semiconductor layer.

[0044] Accordingly, in the nitride semiconductor device fabricated by the foregoing

method, it is possible to achieve a reduction in an operation voltage by reducing contact resistance between the electrode formation region of the III group nitride semiconductor layer and the ohmic electrode. Thus, a heating value during an operation of the nitride semiconductor device can be reduced. As a result, it is possible to realize the nitride semiconductor device which shows a long life time and high reliability.

[0045] Furthermore, the III group nitride semiconductor layer may include a substrate formed of a III group nitride semiconductor. In this case, since the concave/convex shape is formed on the electrode formation region of the substrate, it is possible to enlarge a contact area between the electrode formation region of the substrate and the ohmic electrode. Thus, it is possible to reduce contact resistance between the electrode formation region of the substrate and the ohmic electrode.

[0046] In addition, the step of forming the concave/convex shape may include a step of etching the electrode formation region or a step of polishing the electrode formation region.

[0047] It should be note that in the case where the concave/convex shape is formed on the electrode formation region in a crystal growth surface of the III group nitride semiconductor layer, it is preferable to form the concave/convex portion by etching. Thus, by forming the concave/convex shape by etching, it is possible to form the concave/convex shape while suppressing damages to the crystal formation surface of the III group nitride semiconductor.

[0048] On the other hand, in the case where the concave/convex shape is formed on an electrode formation region of a substrate formed of the III group nitride semiconductor layer, it is preferable to form the concave/convex shape by polishing. In this case, it is possible to form the concave/convex shape easily without damaging a III group nitride semiconductor layer grown on the other plane of the

substrate.

[0049]

[Embodiment] In the following descriptions, as an example of the nitride semiconductor device according to the present invention, a nitride semiconductor laser device will be described.

[0050] Figs. 1 to 3 are section views schematically showing processes of an example of a method of manufacturing a nitride semiconductor laser device according to the present invention.

[0051] First, as shown in Fig. 1(a), a buffer layer 2 formed of an undoped $Al_{0.5}Ga_{0.5}N$, which has a thickness of 250 Å, an undoped GaN layer 3, which has a thickness of 2μm, an n-GaN contact layer 4 formed of GaN doped with Si, which has a thickness of 3 μm, an n-InGaN crack preventing layer 5 formed of $In_{0.1}Ga_{0.9}N$ doped with Si, which has a thickness of 0.1μm, an n-AlGaN clad layer 6 formed of $Al_{0.07}Ga_{0.93}N$ doped with Si, which has a thickness of 1μm, an MQW (multiple quantum well) light emission layer 7 formed of InGaN, a p-AlGaN clad layer 8 formed of $Al_{0.07}Ga_{0.93}N$ doped with Mg, and a p-GaN contact layer 9 formed of GaN doped with Mg, which has a thickness of 0.05μm are sequentially grown on a C(0001) plane of a sapphire substrate 1. Such layers 2 to 9 are grown by, for example, an MOCVD technique (organic metal chemical vapor deposition technique).

[0052]In this case, the MQW light emission layer 7 has a multiple quantum well (MQW) structure, in which four n-InGaN barrier layers formed of $In_{0.02}Ga_{0.98}N$ doped with Si, each having a thickness of 60 nm, and three n-InGaN well layers formed of $In_{0.1}Ga_{0.9}N$ doped with Si, each having 30 nm, are alternately laminated.

[00053] Subsequently, as shown in Fig. 1(b), a region extending from the p-GaN contact layer 9 to the p-AlGaN clad layer 8 is partially etched by a reactive ion etching method (RIE method) or a reactive ion beam etching method (RIBE

method). Thus, a striped ridge portion formed of the p-GaN contact layer 9 and the p-AlGaN clad layer 8 is formed.

[0054] Furthermore, a region extending from a flat portion of the p-AlGaN clad layer 8 to the n-GaN contact layer 4 is partially etched by the RIE method or the RIBE method to a predetermined depth, and thus an n electrode formation region 20 of the n-GaN contact layer 4 is exposed.

[0055] Next, a mask (not shown) formed of Ni, SiO2 or the like is formed on an upper plane of the foregoing ridge portion, both side planes of the ridge portion, an upper plane of the flat portion of the p-AlGaN clad layer 8 and an upper layer of the n electrode formation region 20 of the n-GaN contact layer 4. Thereafter, photoresist is coated onto the mask, patterning using a photomask is performed by use of an exposure method, an interference exposure method, an electron beam (EB) exposure method or the like, and thus forming a predetermined pattern on the photoresist.

[0056] Subsequently, the mask is patterned based on the pattern of the photoresist formed on the above described manner. In this case, for example, a plurality of stripe-shaped opening portions having a predetermined width is formed at predetermined intervals, which extend in a direction parallel to a longitudinal direction of a resonator of the semiconductor laser device.

[0057] Furthermore, by use of the mask in which the foregoing pattern is formed, the p-GaN contact layer 9 in the ridge portion exposed in the opening portions of the mask is etched to a predetermined depth. After such etching, the mask is removed.

[0058] In the above described manner, as shown in Fig.2, stripe-shaped concave and convex portions, which extend in the direction parallel to the longitudinal direction of the resonator of the semiconductor laser device are formed at a predetermined cycle on the surface of the ridge portion of the p-GaN contact layer

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[0059] By the same method as that in the foregoing case where the concave/convex shape is formed on the surface of the p-GaN contact layer 9, stripe-shaped concave and convex portions, which extend in a direction parallel to a longitudinal direction of the resonator of the semiconductor laser device, are formed at a predetermined cycle on a surface of a predetermined region of the n electrode formation region 20 of the n-GaN contact layer 4.

[0060] It should be noted that the cycle of the concave/convex shape in this case is equal to a value obtained by adding a width of one convex portion and a width of a concave portion adjacent to this convex portion.

[0061] Herein, in the above described description, the example in which the concave portion and the convex portion are formed on the surface of the n-GaN contact layer 4 after the concave portion and the convex portion are formed on the surface of the p-GaN contact layer 9 is described. However, the concave portion and the convex portion may be formed on the surface of the p-GaN contact layer 9 after the concave portion and the convex portion are formed on the surface of the n-GaN contact layer 4.

[0062] As shown in Fig. 2 (d), after the concave/convex shapes are formed on the surfaces of the n-GaN contact layers 9 and 4 in the above described manner, an insulating film 12 formed of SiO_2 or the like is formed on both sides of the ridge portion, an upper plane of the flat portion of the p-AlGaN clad layer 8, a side plane extending from the p-AlGaN clad layer 8 to the n-GaN contact layer 4, and an upper plane of the n-GaN contact layer 4 except the n electrode formation region 20.

[0063] Furthermore, as shown in Fig. 3(e), a Ni film and an Au film are sequentially laminated so as to cover the concave portion and the convex portion formed on the surface of the p-GaN contact layer 9, thus forming a p electrode 10.

[0064] Furthermore, as shown in Fig. 3(f), an Al film and a Ti film are sequentially laminated so as to cover the concave portions and the convex portions formed on the surface of the n electrode formation region 20 of the n GaN contact layer 4.

[0065] In the above described manner, a semiconductor laser device 100 is fabricated. In the semiconductor laser device 100 fabricated by the foregoing method, the p electrode 10 is formed on the p-GaN contact layer 9, the surface thereof having the concave/convex shape. For this reason, compared to the case where p electrode is formed on the upper plane of the p-GaN contact layer having the flat surface, a contact area between the p electrode 10 and the p-GaN contact layer 9 is larger. Accordingly, in such semiconductor laser device 100, a reduction in contact resistance between the p-GaN contact layer 9 and the p electrode 10 is achieved. Thus, also in the p-GaN contact layer 9 where it is difficult to make carrier concentration high, a good ohmic contact with the p electrode can be obtained.

[0066] Furthermore, in the semiconductor laser device 100, an n electrode 11 is formed on the n-GaN contact layer 4 having the concave/convex shaped surface. For this reason, compared to the case where the n electrode is formed on the n-GaN contact layer having the flat surface, a contact area between the n electrode 11 and the n-GaN contact layer 4 is larger. Accordingly, in such semiconductor laser device 100, a reduction in contact resistance between the n-GaN contact layer 4 and the n electrode 11 can be achieved, and a good ohmic contact with the n electrode can be obtained.

[0067] As described above, in the foregoing semiconductor laser device 100, by forming the concave/convex shape on the surfaces of the p-GaN contact layer 9 and the n-GaN contact layer 4, the contact resistance with the p electrode 10 and with the n electrode 11 can be reduced, thus achieving a reduction in an operation voltage.

[0068] Accordingly, in the semiconductor laser device 100, it is possible to suppress a heat generation during an operation of the device. For this reason, it is possible to realize the semiconductor laser device which shows a long life time and a high reliability.

[0069] Herein, a cycle a of the plurality of stripe-shaped concave and convex portions formed on the p-GaN contact layer 9 of the semiconductor laser device 100 is preferable to be set to several to several ten μm.

[0070] In this case, as the cycle a of the concave and convex portions is smaller, the contact area between the p electrode 10 and the p-GaN contact layer 9 is preferably larger. Accordingly, a preferably situation is brought about. However, it is difficult to form concave and convex portions having a cycle within a smaller range than that of the cycle a by etching. Accordingly, by setting the cycle a of the concave portion and the convex portion to a value within the foregoing range, the concave/convex portions can be formed easily by etching, and an increase in the contact area between the p electrode 10 and the p-GaN contact layer 9 can be fully achieved.

[0071] Furthermore, a depth b of the concave portion in the stripe-shaped concave/convex shape formed on the surface of the p-GaN contact layer 9 is preferable to set to several ten to several hundred nm. It should be noted that the depth b of the concave portion depends on a thickness of the p-GaN contact layer 9 and the depth b of the concave portion is preferable to be set in order that a thickness t_1 of a region under the concave portion of the p-GaN contact layer 9 is equal to 50 nm or more.

[0072] Furthermore, in the above described descriptions, the case where widths of the concave and convex portions formed on the surface of the p-GaN contact layer 9 are equal to each other was described. However, the widths of the concave and convex portions may be different from each other.

[0073] On the other hand, a cycle c of the plurality of stripe-shaped concave and convex portions formed on the n-GaN contact layer 4 of the semiconductor laser device 100 is preferable to be set to several to several ten μm.

[0074] In this case, as the cycle c of the concave and convex portions is smaller, the contact area between the n electrode 11 and the n-GaN contact layer 4 is preferably larger. However, it is difficult to form concave/convex shape having a cycle within a range smaller than that of the cycle c. Accordingly, by setting the cycle c of the concave portion and the concave portion to the foregoing range, it is possible to form the concave/convex shape easily by etching, and it is possible to achieve the increase in the contact area between the n electrode 11 and the n-GaN contact layer 4 fully.

[0075] Furthermore, a depth d of the concave portion in the concave/convex shape on the surface of the n-GaN contact layer 4 is preferable to be set to several hundred nm to several μm. It is noted that the depth d of the concave portion depends on a thickness of the n-GaN contact layer 4 and the depth d of the concave portion is preferable to be set in order that a thickness t_2 of a region under the concave portion of the n-GaN contact layer 4 is equal to 2 μm or more.

[0076] Furthermore, in the above described descriptions, the case where widths of the concave and convex portions formed on the surface of the p-GaN contact layer 4 are equal to each other was described. However, the widths of the concave and convex portions may be different from each other.

[0077] In the foregoing semiconductor laser device 100, the cycle a of the concave/convex shape formed on the surface of the p-GaN contact layer 9 and the depth b of the concave portion formed thereon may be equal to the cycle c of the concave/convex shape formed on the surface of the n-GaN contact layer 4 and the depth d of the concave formed thereon, or alternatively may be different from each other.

[0078] Furthermore, section profiles of the stripe-shaped concave and convex portions formed on the surfaces of the p-GaN contact layer 9 and the n-GaN contact layer 4 are not limited to the above described ones, and it suffices that section profiles other than these profiles, for example, a saw tooth-shaped section profile may be adopted.

[0079] Furthermore, in the above described descriptions, the case where the stripe-shape concave and convex portions are periodically formed on the surfaces of the p-GaN contact layer 9 and the n-GaN contact layer 4 was described. However, the stripe-shaped concave and convex portions may be formed irregularly on the surfaces of the p-GaN contact layer 9 and the n-GaN contact layer 4.

[0080] Furthermore, in the foregoing semiconductor laser device 100, the case where the concave/convex shape composed of the stripe-shaped concave and convex portions is formed on the surfaces of the p-GaN contact layer 9 and the n-GaN contact layer 4 was described. However, the concave/convex shape may be formed on the surfaces of these layers 9 and 4 by forming dispersively arranged concave or convex portions having various shapes on the surfaces of the layers 9 and 4.

[0081] Furthermore, in the foregoing semiconductor laser device 100, the case where the concave/convex shape is formed on the surfaces of the p-GaN contact layer 9 and the n-GaN contact layer 4 was described. However, the concave/convex shape may be formed only on the surface of the p-GaN contact layer 9. In this case, since contact resistance between the p electrode 10 and the p-GaN contact layer 9 is reduced, it is possible to reduce an operation voltage of the semiconductor laser device 100.

[0082] Alternatively, the concave/convex shape may be formed only the surface of the n-GaN contact layer 4. In this case, since contact resistance between the n

electrode 11 and the n-GaN contact layer 4 is reduced, it is possible to reduce an operation voltage of the semiconductor laser device 100.

[0083] In the above described descriptions, the case where the n-contact layer formed of n-GaN was described. However, in order to achieve a confine effect of light to the MQW light emission layer 7 effectively, an n-AlGaN contact layer formed of n-AlGaN having Al composition of 1 to 2 % may be formed.

[0084] Herein, since the n-AlGaN contact layer containing aluminium (Al) has lower carrier concentration compared to that of the n-GaN contact layer, contact resistance with the n electrode 11 is higher. In this case, however, since the concave/convex shape is formed on the surface of the n-AlGaN contact layer, it is possible to fully reduce the contact resistance with the n electrode 11 even though the n-AlGaN contact layer contains aluminium. Accordingly, in this case, a semiconductor laser device is realized, which is capable of achieving a reduction in an operation voltage and which is capable of effectively performing confinement of light to the MQW light emission layer 7.

[0085] In the above described descriptions, the case where the stripe-shaped concave and convex portions extending in a direction parallel to the longitudinal direction of the resonator of the semiconductor laser device are formed on the surfaces of the p-GaN contact layer 9 and the n-GaN contact layer 4 was described. However, the stripe-shaped concave and convex portions may be formed on a direction other than that described above. Descriptions for this case will be made below.

[0086] Fig. 4 is a schematic section view showing another example of a semiconductor laser device according to the present invention. Fig. 4(a) shows a section of the semiconductor laser device in a direction perpendicular to a longitudinal direction of a resonator. Furthermore, Fig. 4(b) shows a section taken along the line A-A of Fig. 4(a), that is, a section of the semiconductor laser

device in a direction parallel to the longitudinal direction of the resonator.

[0087] The semiconductor laser device 101 shown in Fig. 4 has the same structure as that of the semiconductor laser device 100 of Fig. 3(f) except for the following matters.

[0088] The semiconductor laser device 101 has a p-GaN contact layer 90 in which a plurality of stripe-shaped concave and convex portions extending in the direction perpendicular to the longitudinal direction of the resonator, that is, a direction parallel to an end face of the resonator. That is, the semiconductor laser devices 101 and 100 are different from each other in the directions in which the stripe-shaped concave and convex portions formed on the p-GaN contact layer 90.

[0089] Since the concave/convex shapes are formed on the surfaces of the p-GaN contact layer 90 and the n-GaN contact layer 4 in such semiconductor laser device 101, it is possible to reduce an operation voltage of the semiconductor laser device 101 by reducing contact resistance between the p electrode 10 and the p-GaN contact layer 90 and contact resistance between the n electrode 11 and the n-GaN contact layer 4.

[0090] Accordingly, in the semiconductor laser device 101, it is possible to suppress a heat generation during an operation of the semiconductor laser device 101, leading to a realization of a semiconductor laser device having a long life time and a high reliability.

[0091] Herein, in this case, particularly, the concave/convex shape formed on the surface of the p-GaN contact layer 90 constitutes a diffraction grating. Specifically, such semiconductor laser device 101 corresponds to a distribution feedback (DFB) laser device having the diffraction grating.

[0092] Specifically, since a cycle structure composed of the plurality of stripe-shaped concave and convex portions extending in the direction perpendicular to the longitudinal direction of the resonator is formed on the

surface of the p-GaN contact layer 90 in the semiconductor laser device 101, a refractive index of the MQW light emission layer 7 varies periodically.

[0093] For example, in the semiconductor laser device 101, in which the cycle e of the concave/convex shape on the p-GaN contact layer 90 is 0.246 μm; a refractive index of the MQW light emission layer 7 is 2.5; and an oscillation wavelength of a laser beam is 0.41 μm, light generated in the MQW light emission layer 7 is a third-order diffraction light, and the semiconductor laser device can perform a laser oscillation in a single longitudinal mode. Accordingly, in such semiconductor laser device 101, an oscillation wavelength of the laser beam does not change even when a current value is changed. It is possible to allow the semiconductor laser device 101 to stably oscillate a laser beam having a wavelength of 0.41 μm. Accordingly, in the semiconductor laser device 101, it is possible to realize a good device characteristic.

[0094] Furthermore, in the semiconductor laser device 101 in which the concave/convex shape formed on the surface of the p-GaN contact layer 90 constitutes the diffraction grating, it is possible to allow the semiconductor laser device 101 to oscillate the laser beam having a desired wavelength in the single longitudinal mode.

[0095] The same is true of a depth f of the concave portion in the concave/convex shape formed on the surface of the p-GaN contact layer 9 as in the case of the depth b of the concave portion in the concave/convex shape of the p-GaN contact layer 9 of the semiconductor laser device 100.

[0096] In the foregoing semiconductor laser devices 100 and 101, the case where the stripe-shaped concave and convex portions are formed on the surfaces of the p-GaN contact layers 9, 90 and the n-GaN contact layer 4 along one direction was described. However, the stripe-shaped concave and convex portions may be formed along a plurality of different directions.

[0097] For example, stripe-shaped concave and convex portions extending in the direction parallel tot the longitudinal direction of the resonator may be formed on the surfaces of the p-GaN contact layers and the n-GaN contact layer as in the semiconductor laser device 100. In addition, the stripe-shaped concave and convex portions extending in the direction perpendicular to the longitudinal direction of the resonator may be formed on the surfaces of the p-GaN contact layer and the n-GaN contact layer as in the semiconductor layer 101. The stripe-shaped concave and convex portions extending to the two directions may be made to be perpendicular to each other, and a grating-shaped concave/convex shape may be formed.

[0098] Figs. 5 to 7 are section views schematically showing processes of another example of a method of manufacturing a semiconductor laser device according to the present invention.

[0099] First, as shown in Fig. 5(a), on a n-GaN substrate 21 doped with Si, which has a thickness of 100 to 170 μm, an n-InGaN crack preventing layer 22 formed of $In_{0.1}Ga_{0.9}N$ doped with Si, which has a thickness of 0.1 μm; an n-AlGaN clad layer 23 formed of $Al_{0.07}Ga_{0.93}N$ doped with Si, which has a thickness of 1μm; an MQW light emission layer 24; a p-AlGaN clad layer 25 formed of $Al_{0.07}Ga_{0.93}N$ doped with Mg; and a p-GaN contact layer 29 formed of GaN doped with Mg, which has a thickness of 0.05 μm are sequentially grown. Such layers 22 to 26 are grown by, for example, an MOCVD technique (organic metal chemical vapor deposition technique).

[0100] It should be noted that the MQW light emission layer 24 has a structure similar to that of the MQW light emission layer 7 of the semiconductor laser device 100 of Fig. 3(f).

[0101] Subsequently, as shown in Fig. 5(b), a region extending from the p-GaN contact layer 26 to the p-AlGaN clad layer 25 is partially etched by a reactive ion

etching method (RIE method) or a reactive ion beam etching method (RIBE method). Thus, a striped ridge portion formed of the p-GaN contact layer 26 and the p-AlGaN clad layer 25 is formed.

[0102] Subsequently, as shown in Fig. 6(c), an insulating film 12 formed of SiO_2 or the like is formed on both side surfaces of the ridge portion and upper surfaces of flat portions of the p-AlGaN clad layer 25.

[0103] Furthermore, as shown in Fig. 6(d), a p electrode 10 is formed of a Ni film is formed on the p-GaN contact layer 26 of the ridge portion.

[0104] Subsequently, as shown in Fig. 7(e), a plane (back plane) on the opposite side of a crystal growth plane of the n-GaN substrate 21 is polished with abrasive having a particle diameter of 10 μm or more. Thus, concave portions and convex portions having no regularity in their two-dimensional arrangement and cycle are formed on the surface of the n-GaN substrate 21. As described above, in this example, the concave portions and the convex portions are randomly formed on the surface of the n-GaN substrate 21 by polishing.

[0105] Finally, as shown in Fig. 7(f), an n electrode is formed by sequentially laminating an Al film and a Ti film on the surface of the n-GaN substrate 21 in which the concave/convex shape is formed, so as to cover the concave portions and the convex portions.

[0106] In the semiconductor laser device 102 fabricated by the foregoing method, the n electrode 11 is formed on the n-GaN substrate 21, the surface of which has the concave/convex shape. For this reason, compared to the case where the n electrode is formed on the n-GaN substrate having the flat surface, a contact area between the n electrode and the n-GaN substrate 21 is larger. Accordingly, in such semiconductor laser device 102, it is possible to reduce contact resistance between the n-GaN contact layer 4 and the n electrode 11.

[0107] Particularly, in this case, even when dope concentration of the n-GaN

substrate 21 is low, deterioration of an ohmic characteristic does not occur during a thermal treatment after the formation of the electrode, and a good ohmic contact between the n-GaN substrate 21 and the e electrode 11 is obtained. Accordingly, in the semiconductor laser device 102, good crystallinity can be realized in the n-GaN substrate 21, and a good ohmic contact between the n-GaN substrate 21 and the n electrode 11 can be obtained.

[0108] As described above, in the foregoing semiconductor laser device 102, by forming the concave/convex-shape on the surface of the n-GaN substrate 21, it is possible to reduce the contact resistance with the n electrode 11, and thereby to reduce an operation voltage of the semiconductor laser device 102. Therefore, in the semiconductor laser device 102, it possible to suppress a heat generation during an operation of the device, and the semiconductor laser device having a long life time and high reliability can be realized.

[0109] Herein, depths of the concave portions of the concave/convex shape formed on the surface of the n-GaN substrate 21 are preferable to be set to several to several ten μm. In this case, the depths of the concave portions may be different from each other. Furthermore, in this case, widths of the concave portions and the convex portions may be arbitrary, and may be irregular. However, the widths of the concave portions and the convex portions are preferable to be small from the viewpoint of increasing a contact area between the n electrode 11 and the n-GaN substrate 21.

[0110] Furthermore, section views of the concave portion and the convex portion formed on the n-GaN substrate 21 are not limited to the above, and may have arbitrary ones formed by polishing.

[0111] In the description of the foregoing semiconductor laser device 102, the case where the concave/convex shape is formed only on the surface of the n-GaN substrate 21 was described. A concave/convex shape, however, may be further

formed on the surface of the p-GaN contact layer 26. In this case, since the contact resistance between the p electrode 10 and the p-GaN contact layer 26 is reduced, an operation voltage of the semiconductor laser device can be more reduced.

[0112] In the foregoing description, the case where the concave/convex shape is formed on the surface of the n-GaN substrate 21 by polishing was described. However, the concave/convex shape may be formed on the surface of the n-GaN substrate 21 by etching, as in the case of the semiconductor laser device 100. In the case where the concave/convex shape is formed by etching in such manner, a cycle of the stripe-shaped concave and convex portions formed on the surface of the n-GaN substrate 21 is preferable to be set to several to several ten μm.

[0113] It is possible to form the concave/convex shape more easily in the case where the concave/convex shape is formed by polishing as in this example than the case where the concave/convex shape is formed by etching.

[0114] Herein, in the case where the concave/convex shape is formed on the surface of the n-GaN substrate 21, the formation of the concave/convex shape by polishing never damages a crystal growth layer formed on the other surface of the substrate. Contrary to this, in the case where the concave/convex shape is formed on the surface of the crystal growth layer as in the case of the semiconductor laser device 100, the formation of the concave/convex shape by polishing may damage the crystal growth layer.

[0115] In the foregoing semiconductor laser device 100, 101 and 102, the constitutions of the layers are not limited to the above described ones, and the layers may be composed of a nitride semiconductor containing at least one of Al, Ga, In, B and Ti.

[0116] Furthermore, in the foregoing description, the case where the present invention is applied to the semiconductor laser device was described. It is

possible to apply the present invention to a semiconductor light emission device other than the semiconductor laser device and a semiconductor device other than the semiconductor light emission device.

[Brief Description of the Drawings]

[Figure 1] Figs. 1(a) and 1(b) are schematic section views showing processes of an example for a manufacturing method of a semiconductor laser device according to the present invention.

[Figure 2] Figs. 2(c) and 2(d) are schematic section views showing processes of an example of a manufacturing method of a semiconductor laser device according to the present invention.

[Figure 3] Figs. 3(e) and 3(f) are schematic section views showing processes of an example of a manufacturing method of a semiconductor laser device according to the present invention.

[Figure 4] Figs. 4(a) and 4(b) are schematic section views showing another example of a semiconductor laser device according to the present invention.

[Figure 5] Figs. 5(a) and 5(b) are schematic section views showing another example of a method of manufacturing a semiconductor laser device according to the present invention.

[Figure 6] Figs. 6(c) and 6(d) are schematic section views showing another example of a method of manufacturing a semiconductor laser device according to the present invention.

[Figure 7] Figs. 7(e) and 7(f) are schematic section views showing another example of a method of manufacturing a semiconductor laser device according to the present invention.

[Figure 8] Fig. 8 is a schematic section view showing an example of a conventional semiconductor laser device.

[Explanation of Reference Numerals]

1......sapphire substrate; 2....buffer layer; 3.....undoped GaN layer; 4......n-GaN contact layer; 5,22......n-InGaN crack preventing layer; 6, 23.....n-AlGaN clad layer; 7, 24.....MQW light emission layer; 8, 25....p-AlGaN clad layer; 9, 26.....p-GaN contact layer; 10.....p electrode; 11....n electrode; 12.....insulating film; 21....n-GaN substrate; and 100, 101, 102.....semiconductor laser device

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F term (reference) 4M104 AA04 BB05 CC01 DD08 DD24
FF31 GG04 HH15
5F041 CA40 CA74 CA91 CA93 CA98
CA99
5F073 AA11 AA13 AA51 AA61 AA74
CA07 CB05 CB07 DA25 DA35
EA23 EA29